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Real-Time Virtual Landscapes in Landscape and Urban Planning

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In landscape and urban planning, public participation and interactivity become more and more an issue. Real-time virtual 3D landscapes represent communication tools that allow experts as well as non-experts to use, explore, analyze, and understand landscape information. In our contribution, we describe the architecture and functionality of an interactive, participatory system, Lenné3D, which facilitates creation, management, and distribution of real-time virtual landscapes. Systems supporting virtual landscapes must handle the inherent complexity of their components, in particular building and vegetation objects. In our approach, real-time virtual landscapes are based on 3D maps as underlying concept for composing and managing virtual landscape models. They are complemented by 3D vegetation models, which use botanical-based 3D plant models. To cope with the massive geometric complexity of virtual landscapes, multiresolution schemes need to be applied to buildings as well as to vegetation objects. The concepts have been successfully implemented within the Lenné3D system as demonstrated by a case study.

KEYWORDS

Geovirtual Environments, Landscape Planning, Landscape Modeling, Virtual Reality, 3D Maps.

INTRODUCTION

Virtual landscapes traditionally have manifold applications in landscape planning and landscape architecture. They represent a general type of geovirtual environment (GeoVE) that includes 3D terrain models, 3D building models, and 3D vegetation models. Due to their generality, virtual landscapes can be applied to a broad range of applications and systems in geo-sciences, such as in the fields of environmental information systems, disaster management systems, homeland security applications, and facility management systems. Insofar, virtual landscapes can be considered as an import class of user interface paradigm for spatial information.

The paper reports on concepts and experiences of the Lenné3D system, a system for creating, managing, and real-time rendering of complex virtual landscapes. It has been motivated by the need for an interactive, intuitive tool and decision-support system for exploring, analyzing, and communicating landscape plans and impressions to both experts and non-experts [17]. It aims at supporting the dialogue on community landscape and urban planning as well as decision-making within public participatory processes. In Fig. 1 the virtual landscape is currently used in public participation in the management of landscape change.

LIMITATIONS IN COMMUNICATING LANDSCAPE INFORMATION

Only in rare cases planning contents in public participatory projects are mediated to the public by means of understandable and visually interesting presentations. Fundamental limitations result from the human landscape perception, which is based on a complex aesthetic process. Only through the intellectual processing of what has been seen, the visual information of a landscape detail turns into what we call *landscape*. Hence, the cognitive efforts are high [22]. The aesthetic product "landscape" mainly consists of the factors "education", "experience" and "enjoying observation" (contemplation). This connection is well familiar to the "landscape planning profession".

Figure 1: Example of a real-time virtual landscape of the Swiss UNESCO Biosphere Reserve Entlebuch (Lenné3D in cooperation with ETH Zurich / VisuLands).

There is usually a lack of concrete, visual representation of the landscape known to the participants from their own experience although people are curious to know "What would it look like?" Abstract and graphically often insufficient maps, imprecise and manipulative perspective presentations, non-representative still pictures (e.g., montage-based imagery) or high-speed fly-throughs from bird's eye views based on cost-intensive, manually modeled 3D scenes neither convince the stakeholders nor the public. Yet, understanding of the outcomes and consequences of landscape planning decisions is generally poor among the public and their elected representatives. The communication and public participation process seems to be in need of improvement.

POTENTIALS OF REAL-TIME VIRTUAL LANDSCAPES

Participative planning approaches need tools facilitating the communication between stakeholders and planners, and assisting in the understanding and assessment of the consequences of future changes. As Tress and Tress [19] point out: "It would be ideal to have a powerful and photo-realistic GIS-based visualization tool with dynamic characteristics that would show landscape from the perspective of a moving observer" (p. 173). Appleton et al. [2] conclude that there is no "universal landscape visualization solution", and that current technology forces users to make trade-offs in detail and interactivity. They see a market gap for a visualization tool that can be used in combination with GIS, and predict that future visualization technology will move towards the combined goals of availability, geographic detail, realism and interactivity. With respect to technology, a case study was undertaken, in which a participatory landscape project was supported with interactive 3D computer simulations created by adapting computer-games [13].

Real-time virtual landscapes enable the intuitive communication of complex, space-related information [5] and enable public participation in landscape and urban planning. Technically, they are based on real-time 3D computer graphics [1] and their ability to cope with complex, large-scale 3D scene contents. However, interactive visualization tools matching the special needs of landscape and urban planning only exist in their beginnings.

Within the Lenné3D project we could identify critical requirements and features such as interactive photorealistic rendering, interactive illustrative rendering, direct manipulation of landscape objects, support for visualizing traditional GIS raster and vector data, convincing representation of vegetation objects, and the ability to chose and switch between any perspective ranging from map-like views, bird's eye views, and human observer views. In a sense, real-time virtual landscapes translate Repton's idea [6] with his Red Books to draw different planning situations from the viewer's perspective into a new, digital media-based dimension.

3D LANDSCAPE MODELS

A virtual landscape represents part of a real or imaginary landscape by a *landscape model*. The landscape model is composed in a hierarchical way based on *landscape objects*. They include the digital terrain model (DTM), 2D imagery data such as aerial photography or topographic maps, 2D planning data such as cadastre data or street networks, 3D building data, and 3D biotope and vegetation data. The landscape model can be complemented by *graphics objects* (e.g., annotations, virtual sky, legends) and thematic data relevant to the application domain (e.g., landuse data, contamination data).

From a software engineering perspective, it is important that objects of virtual landscapes do not only define attribute data but also functionality represented as methods. For example, a building object defines properties such as ground polygon, height, roof type, number of floors etc. In addition, it provides functionality to construct the roof geometry according to the roof type, the walls according to the building height and ground polygon, and it can calculate building-specific properties such as the number of square meters available or its volume.

In particular, *object-oriented modeling of vegetation objects* has been one of the major innovations in the presented approach for real-time virtual landscapes. For example, an object of type "alley" is instantiated as a group of trees, placed parallel along a street with defined distances. If the course of the street, the distance, or the tree type is changed the alley object automatically re-instantiates its components. This way, built-in functionality becomes directly available to the landscape modeler and provides higher-level functionality compared to purely virtual reality systems.

FUNCTIONALITY OF REAL-TIME VIRTUAL LANDSCAPE SYSTEMS

From a technical point of view, a real-time landscape system can be characterized by the following functionality:

- *Real-Time Rendering* – allows us to interactively operate, explore, and analyze landscape models;
- *Plant Models* – need to be detailed, three-dimensional, and botanically accurate to be convincing and useful landscape objects;
- *Vegetation Arrangement* – includes the instantiation, distribution, orientation, of plant models according to characteristics of plant species, soil type, topography and other relevant parameters [18];
- *Landscape Editing* – required to directly manipulate landscape model objects [14] without having to switch between a 2D conceptual, map-based view and a virtual reality 3D view;
- *Landscape Rendering* – should support different presentation styles such as photorealistic 3D rendering, illustrative 3D rendering, and cartographic 2D representations – to be implemented as real-time rendering techniques;
- *Landscape Interaction* – requires navigation tools and support for orientation in the 3D geovirtual environment, in particular, the user should be able to select between different navigation tools such as walking and flying;
- *Scalability* – the rendering techniques used should be able to process massive data sets, which typically occur even for small virtual landscapes (e.g., aerial photography of 300 GB for a middle-size town in a resolution of 10cm), using multiresolution algorithms and data structures;
- *Interoperability* – requires that common formats for geo data can be processed. For building models and vegetation models there are still no industry standards available but several XML-

based first approaches exist;

- *Digital Rights Management (DRM)* – protects the digital contents of virtual landscapes and, thereby, provides means to control the usage and distribution of virtual landscapes. DRM is a prerequisite for using virtual landscapes as a communication tool between different target groups to comply with license and usage rights [11].

ARCHITECTURE OF THE LENNÉ3D SYSTEM

The architecture of our system (Fig. 2) consists of two core subsystems, the editor system and the presentation system. Both communicate via landscape model, which are represented as a collection of hierarchically structured objects and encoded by XML documents.

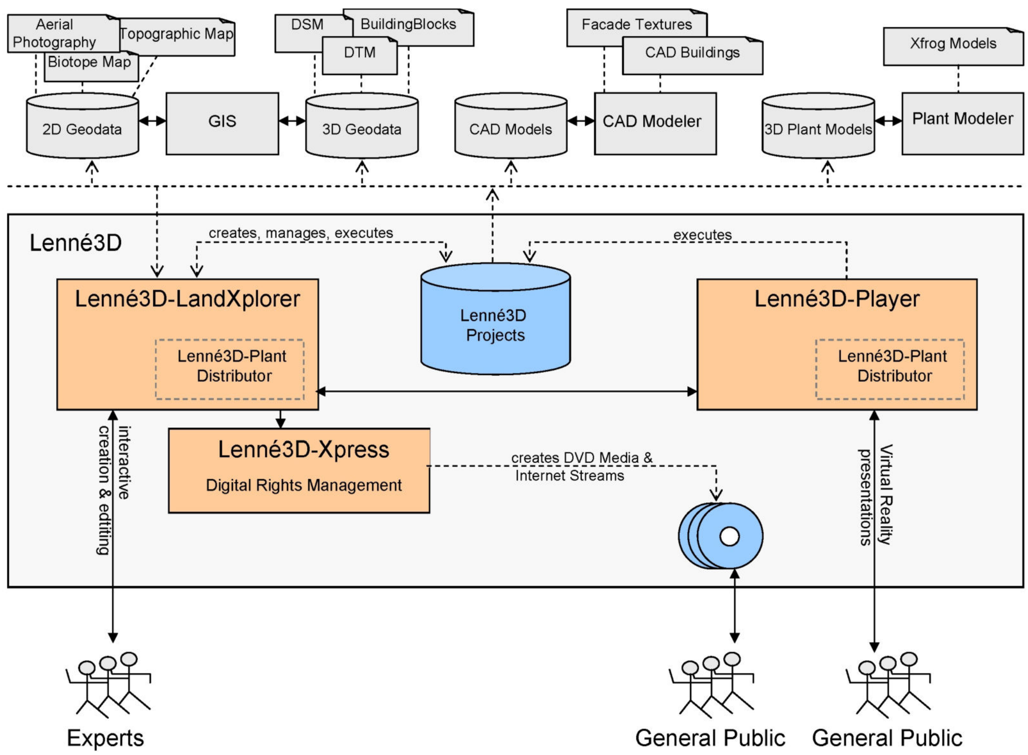

Figure 2: Architecture of the Lenné3D system with main components and data flow.

The editor system Lenné3D-LandXplorer is responsible for creating, managing, and storing the virtual landscape model. It provides the user interface for the real-time landscape system. Implemented as desktop application, users can directly compose and manage their virtual landscape projects based on 3D maps.

The presentation system is responsible for real-time rendering of complex landscape models. It can be used within the editor, but also as a stand-alone application. It provides optimized rendering techniques for presenting complex landscapes but does support the full range of editing features due to the optimizations.

Both, editor and player, rely on the plant distribution subsystem. It takes care of instantiating, placing, and configuring vegetation objects. Since plant distributions are determined on-demand, editor and player require its services.

In addition, the system defines a DRM subsystem, which is responsible for exporting virtual landscape projects as stand-alone applications containing all required geodata. The DRM system processes and transforms a given virtual landscape model, in particular, it compresses and encrypts geodata.

From a user's point of view, the subsystems are not directly recognizable but this structure provides a manageable and component-oriented basis for implementation. Most importantly, no proprietary geodata formats need to be developed except the XML scheme that bundles all resources of a virtual landscape model.

EDITING VIRTUAL LANDSCAPES

The editor system serves as authoring tool and expert system for virtual landscapes. In the Lenné3D system, the LandXplorer geovisualization system [10] has been integrated and extended as editor system. It provides enhanced functionality for constructing and designing 3D geovirtual environments.

The editor system offers three categories of building blocks for these environments:

- *Geometry objects* used to represent geodata and geo-objects. Examples include multiresolution digital terrain models and raster-data layers.
- *Behavior objects* used to specify interaction and animation capabilities available to a geovirtual environment. Examples include animated camera bookmarks or dynamic textures.
- *Structure objects* used to hierarchically organize the components of a geovirtual environment. Examples include component groups and information layers.

For virtual landscapes, information layers play an important role because most geodata to build a virtual landscape is organized as raster-data layer or vector-data layer. Raster-data layers represent rasterized 2D geodata such as aerial photography, topographic maps, or terrain shadings. They are positioned on top of the digital terrain surface according to their geo-coordinates. Each layer can have different resolution and extension, and it can overlap with other layers.

Vector-data layers represent vector-based graphics including geo-referenced points, lines, polygons, and curves. Prominent examples include Shapefiles and 2D vector graphics. The layers are rasterized in a view-dependent way in real-time. Therefore, no pre-rasterization is required. In addition, each object contained in a vector-data layer can be identified and directly edited in the 3D view. Fig. 3 shows an example of editing a 2D polygon in 3D.

Figure 3: Direct creation and manipulation of 2D vector-based objects in 3D used to interactively create and modify virtual landscape models.

Generally, information layers are projected on top of the terrain surface as terrain textures. Alternatively, they can be projected on virtual (glass) planes located at a specified constant height above the terrain. All information layers can be enabled and disabled individually. Layers can be combined by defining the imaging operation that is applied to the corresponding textures during rendering, for example, weighted addition or modulation. For rendering a virtual landscape having multiple information layers, we apply multitexturing, that is, the terrain surface is textured by multiples textures at a time. For example, an aerial photography can be visually combined with an information layer containing a street network.

There is no restriction regarding the number of information layers and their capacity. In our use cases, up to 32 information layers can be processed in real-time. The multiresolution texturing technique [9] underlying the information layer concept operates on virtually unlimited raster data sets, which can process up to 300 GB in real-time. Both, a flexible layering scheme and a robust multiresolution treatment of information layers are necessary if real-world data for landscapes should be processed. In general, not only the planning area but also its surroundings need to be incorporated into the virtual landscape model.

DOCUMENTING VIRTUAL LANDSCAPES

The visual documentation functionality refers to those functions that help authors to document a virtual landscape. The documentation can aim at giving project-specific information to the expert who is exploring or analyzing the landscape, or it can give general information to the intended audience a virtual landscape is presented. We identified three types of visual documentation functionality: annotations, camera settings, and snapshots.

Annotations place labels or icons in the 3D scenery but they treated as distinguished geo-objects. An annotation can be created by texts or images, and is always oriented towards the viewer.

Snapshots denote captured contents of a 3D view. To support documenting virtual landscapes, we identified two principal types of snapshots functionality, virtual panorama views and high-resolution images. For panorama views, the author defines a center from which virtual snapshots are taken in a 360° rotation. With panorama views, authors can directly export part of the virtual landscape in a still semi-interactive fashion and without requiring a specific software installation on the user's site.

High-resolution images denote screen shots with a resolution that exceeds the physical screen resolution, for example, 10,000 x 10,000 pixels. To compute those images, the camera view is decomposed into a number of tiles, each of which is rendered separately, and the resulting subimages are combined into a single image. With high-resolution images, an important demand of landscape planners for high-quality, physical printings such as posters can be satisfied.

MANAGING BUILDINGS IN VIRTUAL LANDSCAPES

Buildings occur in most virtual landscapes although they are sometimes not the dominant elements in contrast to 3D city model applications. However, they are fundamental objects that need to be supported. In Lenné3D, we distinguish buildings at four levels of quality [16]. Box models are created based on 2D polygonal ground planes with associated heights („LOD-1 buildings"). They represent the simplest type of building, suitable in the initial phase of planning virtual landscapes. 3D building geometry with detail façade geometry and roofs ("LOD-2 buildings") represent the next quality level, useful in particular to model far-away buildings such as those in the surroundings. Detailed, textured 3D geometries ("LOD-3 buildings"), and to a certain degree architectural building models including interior designs ("LOD-4 buildings"), are required for areas of high interest in virtual landscapes. The Lenné3D system supports all levels of quality, and provides a semi-automated process to building objects.

For each building and building part, properties such as address, numbers of floors, or building usage are defined. In particular, the editor allows for assigning façade textures and roof textures to buildings, and supports the migration of LOD-1 buildings to LOD-2 and LOD-3 buildings.

In addition, virtual landscapes require general 3D objects to be imported in common 3D data formats such as VRML and Studio Max 3DS. Typically these objects serve to enhance the virtual landscape by technical objects such as bridges, tunnels, trails, etc.

MANAGING VEGETATION IN VIRTUAL LANDSCAPES

We distinguish between *plant modeling,* that is, modeling individual plant types (e.g., an 100-year old oak tree) from *vegetation modeling*, that is, modeling a setting of plant objects in a specific area (e.g., a forest of oak trees).

Vegetation modeling is broken down into two stages [18]. In the first stage, pedological maps and/or relief data (e.g., altitude, exposition, slope) or other expert data are combined with vegetation referenced spatial data (e.g., maps of biotope types) to produce more or less homogeneous parts (so-called "geoCells") in the landscape. These clippings will then be combined with relevé data at the next stage. The dispersion of every plant (model) within the "geoCell" is automatically computed, based on the sociability of the particular species (or on a manually given distribution path). Depending on the size of the sample area, hundreds of thousands, up to several billions of single plant individuals can result, whose locations must be turned over to the editor and player.

Plant modeling represents a challenging task, particularly because botanical knowledge is required and manual processes are involved, for example, to collect images of plant parts, to scan leaf textures, to produce variants of a single plant, and to set up properties for a plant type. Although plants appear in countless computer graphics works, a botanical-based, three-dimensional approach to plant modeling is still an active research area.

Figure 4: 3D plant model of an artichoke.

Each *plant model* is defined by its 3D geometry and a collection of textures used to achieve a high degree of photorealism. As modeling tool, the ***xfrog*** system (greenworks organic software) is deployed. The xfrog plant modeler offers object-oriented building blocks such as nodes for leafs, branches, arrangements, curves, and variations [7]. Based on hierarchical graph-based plant specifications, the resulting 3D geometry of a single plant can be derived.

In the Lenné3D project, plant modeling experts take care of building up a plant library, which currently contains detailed plant models for more than 500 plant species that occur in Europe. The library represents for each wooden plant specie its state in springtime and wintertime, and provides variants for different growth states. In addition, landscape planning-relevant properties are specified as far as possible. In Fig. 4, the 3D model of an artichoke is illustrated.

Vegetation modeling is based on specialized information layers, the vegetation layers, which contain biotope and landuse data together with additional GIS thematic data such as topographic data, history, and soil type information. Based on vegetation reference tables, the Lenné3D plant distributor subsystem calculates the plant distribution for a given area, and it assigns plant models to these distributions. A vegetation layer can also contain explicitly placed and instantiated objects, for example, landmark-like trees.

The Lenné3D plant distributor determines the contents and spatial distribution of vegetation layers by heuristic-algorithmic techniques. The distributor also takes into account additional spatial information such as terrain slope, terrain exposition, or landuse type. For example, we can specify an area of bushes by the area polygon, the density in which bushes should occur, and the distribution function, which could specify an exposition range that constrains possible locations for a single bush.

PRESENTING VIRTUAL LANDSCAPES IN REAL-TIME

The virtual landscape presentation system, the player, provides optimized, photorealistic and illustrative rendering functionality for complex virtual landscapes containing up to millions of individual vegetation objects [8]. To achieve rates of at least 16 frames/second, we have to solve a non-trivial problem: reduction of the massive geometric complexity. The complexity results from two facts: 1) A single plant model, say a typical tree, commonly contains between 50,000 and 150,000 textured triangles, whereby large parts are spent on the leafs. 2) The human experience in seeing plants is highly developed. Therefore, observers are critical with respect to "fake plants" constructed with billboards, which may be suitable for far-away rendering of plants but do not allow us to render convincing, detailed trees from a close perspective.

The Lenné3D project has developed new level-of-detail rendering techniques [4, 8] that drastically reduce the geometric complexity, e.g. by point-based and line-based simplification schemata. Roughly speaking, only vegetation directly in front of the camera are rendered with full detail, whereas all other vegetation objects are approximated by 3D points and 3D lines that resemble the overall geometry of the tree. Consequently, with Lenné3D virtual landscapes with a high amount of photorealism become possible. Lenné3D does not rely on billboard-based plant rendering, although recent progress in billboard rendering seems to be attractive (e.g., using sets of slices of billboards).

The Lenné3D player also interprets vegetation layers, and it decides whether to instantiate individual plant objects or to use approximations. For example, once the observer comes close to a lawn area, say up to 20 cm, the individual blades of grass close to the observer are instantiated, in all other cases the lawn area is approximated by simplified geometry and treated as a whole. Fig. 5 shows an example of a complex vegetation-based scene.

Figure 5: Detailed 3D vegetation in a complex, virtual real-time landscape.

The functionality of the player includes:

- Photorealistic, real-time display of virtual landscapes
- Non-photorealistic, real-time display of virtual landscape using illustrative renditions
- Dynamic change between different planning scenarios
- Activation and deactivation of individual buildings
- Activation and deactivation of individual vegetation layers and vegetation objects
- Tools for guided navigation, which restricts the degrees of freedoms to achieve higher usability for non-expert navigation
- Collaborative visualization of the same virtual landscape among a group of users

NAVIGATING THROUGH VIRTUAL LANDSCAPES

Navigation is a key factor for user acceptance of real-time virtual landscapes. Existing GeoVEs frequently suffer from the lack of a proper handling and prevention of confusing or disorientating situations. As Fuhrmann and MacEachrean [12] point out, "core problems for users of these desktop GeoVEs are to navigate through, and remain oriented in, the display space and to relate that display space to the geographic space it depicts." In the Lenné3D system, smart navigation strategies [3] are applied that overcome these problems and give additional features to landscape planners for user guidance:

- Smart navigation strategies interpret user interaction regarding the current view specification, i.e., the parameters of the virtual camera, and determine if the user is about to get into confusing or disorienting situations in an anticipatory way.
- They guide the user away from situations where usual navigation behavior tends to fail.
- They always indicate to the user when the guidance mechanism is operating, so that the user understands the behavior of the smart navigation strategy.
- They allow for constraining the camera according to data quality and the emphasis given to certain parts of the virtual landscape.

With smart navigation strategies we achieve better user acceptance for virtual landscape applications. Particularly, they are useful to inexperienced users because they reduce the need for specific training. Smart navigation strategies split common navigation techniques into two steps. First, the mapping from user interaction events to camera movements takes place. Second, the intended movement is checked against several constraints and modified if necessary.

In the scope of virtual landscapes, navigation is required for both authoring and presentation tasks. However, the actual navigation techniques used are largely the same. In the Lenné3D system, we distinguish between locally operating and globally operating navigation techniques.

Local navigation techniques are anchored by spatial positions such as defined by the center of the visible part of the landscape. The spherical trackball, for example, simulates rotating a virtual sphere enclosing that visible area. Similarly, the conical trackball supports zooming within the virtual cone. In addition, the walking mode, commonly known from computer games, represents an avatar walking in the virtual landscape and provides a pedestrian's perspective. As a characteristic element of local navigation, only part of the geovirtual environment is visible, and the camera remains close to the objects of the virtual landscape.

Global navigation techniques aim at providing a spatial overview and allow for browsing and selecting local areas. In general, the distance between camera and virtual landscape is much larger compared to local navigation techniques. Well-known metaphors include, for example, flying vehicles such as virtual airplane and the virtual helicopter.

For an efficient handling of virtual landscapes, we also need to provide techniques that allow for structuring and personalizing the geovirtual environment. The key concept represents the camera setting, which refers to an actual position and orientation of the virtual camera through which we perceive the virtual landscape. The position and orientation can be recorded, stored, and restored at any time. The camera settings are managed similar to other objects of a virtual landscape, in particular, they can be grouped and organized hierarchically. With a collection of camera settings authors of virtual landscapes can document sites of special interest. It is also possible to derive camera animations from an ordered list of camera settings by animating the switch between two adjacent settings.

Camera settings turn out to be an intuitive tool for non-animation experts. The author of a virtual landscape interactively navigates through the environment. All "best views" are stored as camera settings. Then, they are sorted and optionally re-adjusted. Once the collection of camera settings fulfils all needs, even sophisticated computer animations can be managed and produced in a systematic way.

COLLABORATIVE WORK ON VIRTUAL LANDSCAPES

If virtual landscapes are used for communication on landscape plans, collaborative usage of virtual landscapes becomes important. Lenné3D offers a first, still rudimentary functionality for real-time collaboration on virtual landscape projects. Any number of Lenné3D systems (editors and/or players) can be linked via a general network and synchronized with respect to camera settings and changes in information layers. One system operates as "master" propagating all state changes to all dependent systems.

MANAGING DIGITAL RIGHTS OF VIRTUAL LANDSCAPES

Distributing virtual landscapes raises the question of how an author can control the way a potential user is presenting, exploring, analyzing, modifying, and redistributing contained geoinformation. Geospatial digital rights management provides means of controlling usage of GeoVEs and to improve user guidance and usability.

Generally, Digital Rights Management (DRM) "involves a collection of hardware, software, services, and technologies for persistently governing authorized distribution and use of content and services according to their associated rights" [20]. Its original focus was on models of dissemination and use of intellectual property assets. However, because of DRM's impact on industry and business models, the technology is increasingly being used to define techniques and mechanisms for identifying, describing, packaging, distributing, and controlling the use of digital contents. For the general characteristics of DRM systems see Koenen et al. [15].

The DRM technology becomes necessary when legal aspects such as copyright or license issues are relevant and need to be fulfilled by authors. For example, a geodata trading company which collects, composes, and refines geodata most likely has to follow different contractual obligations for each geodata source. An effective and efficient solution would be for the company to deliver composed, refined geodata by means of 3D maps that are restricted in their usage according to the contractual situation. As long as GeoVEs and their constituent geodata are used, distributed, and modified within a trusted and known context, protection and controlling issues of the data and their visualizations can be ignored, but once geodata and GeoVEs are targeted in an open context, these issues appear to be critical due to technical, legal, and strategic implications. In the case of virtual landscapes, we investigated this aspect in deep because it is one of our goals to be able to distribute virtual landscapes to a possibly large audience on diverse media such as Internet and DVD.

Constraints have the main objective to adjust the degrees of freedom of usage and redistribution by restricting and controlling constituent components of GeoVEs. Technically, constraints can be modeled as components of GeoVEs. These components are constructed and managed similar to geometry, appearance, interaction, or animation building blocks.

Three different groups of constraint types we applied in the Lenné3D system are:

- Spatial constraints — These constraints restrict spatial parameters of GeoVEs such as camera position, orientation, and movement;
- Structural constraints — These constraints restrict operations that modify GeoVE components, such as replacing or adding components;
- Redistribution constraints — These constraints define the properties of redistributed GeoVEs.

A detailed discussion on constraints as means for controlling GeoVEs is given in [11]. The Lenné3D-Xpress subsystem provides services to encapsulate a virtual landscape project together with a customized version of the editor and player software into a single, executable unit. It contains the corresponding compressed and encrypted geodata, and it cannot be decomposed anymore. The executable typically is distributed on DVD or via Internet.

USE CASE "VIRTUAL GARDENS"

A prominent use case for the presented concepts and implementation of real-time virtual landscapes has been implemented by reconstruction of a "lost garden", the former "Italian cultural showpiece" was a jewel of the Potsdam-Berlin (Germany) park and garden landscape, which was largely arranged by Peter Joseph Lenné (1789–1866) two centuries ago, and is now designated part of the UNESCO world cultural heritage.

The garden was laid down in 1834 to the west of the Roman Baths in Sanssouci park in order to complete the atmosphere of an Italian country villa as created by the Roman baths. Fig. 6 shows a historic 2D map of the garden, and Fig. 7 contains a snapshot of its virtual counterpart. Grape vines and pumpkins once grew like garlands scalloping between elm and mulberry trees, between ornamental and useful plants from the Mediterranean, thus emphasizing the agricultural character of the Roman Baths. Many of the plants used are not winter-hardy in central Europe, their cultivation is demanding and their care is very labor intensive. Within only 50 years after its creation nothing remained of the garden.

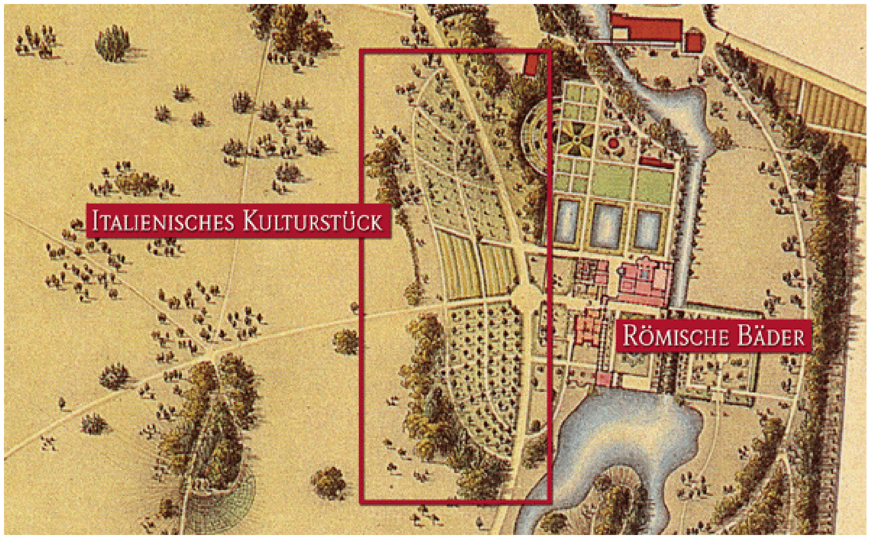

Figure 6: Historic map of the lost Italien Garden of Park Sanssouci, Potsdam (© SPSG).

Landscape planners, officials, and the general public are recently discussing to reconstruct the lost garden in the long run. This was the motivation to apply the Lenné3D system because it is necessary to first study and understand its structure, composition, and appearance.

Today it would be simple to recreate the system of paths, however the time consuming maintenance of the garden is hardly to be implemented due to a tremendous amount of labor. In this case, a computer simulation is the ideal means to provide experts and the general public with an impression of the former diversity of the horticultural garden. The 3D model of the lost garden was composed jointly by scientists of the garden management of the Foundation for Prussian Palaces and Gardens in Berlin and Brandenburg (SPSG) and the Lenné3D team. As no historical pictures existed, the exact list of plants and the layout of the entire area had to be compiled on the basis of the few general plans, written descriptions and the analogies to historically existing useful plants.

Figure 7: Image of the reconstructed lost Italian Garden of Park Sanssouci, Potsdam, by Lenné3D.

In summer 2004, more than 20,000 people visited the exhibition "Prussian Green. From Royal Court Gardeners to Curators of a Historical Garden Heritage" where the virtually reconstructed Garden of the 19th century was presented to the public using the Lenné3D system within a virtual reality environment. For an enhanced visual garden experience, the Lenné3D presentation system generated images that were projected onto a concave 180° panorama screen (Fig. 8). By means of a tangible interface especially developed for the application, the visitor, standing in the half circle of the screen, is able to choose his own path through the garden in an intuitive manner and thus immerse himself in the virtual world. The lightwheel (Fig. 8) represents the viewer's location and highlights his viewshed on the map. In fact, while most of the visitors became quickly acquainted with the setting, others were confused, expecting that the image detail would move to the opposite direction while rotating the lightwheel to the other. These people probably did not understand the map metaphor of the desk.

Figure 8. Photography of the installed Lenné3D VR system. Visitors of the exhibition could interactively explore the lost Italian Garden of Park Sanssouci, Potsdam.

Our concepts and system has been applied in another major case study, the project "Interactive Landscape Plan" [21] of the township of Königslutter, Germany in cooperation with the University of Hannover, sponsored by the German Federal Office for Nature Conservation (BfN).

CONCLUSIONS

The construction of virtual landscapes that are based on complex geospatial information spaces requires a systematic, object-oriented approach as demonstrated by the Lenné3D-LandXplorer system. In addition, virtual landscapes require an optimized approach for plant modeling and vegetation modeling, exemplified by Lenné3D-Player system. Current GIS solutions do not concentrate on authoring and presentation functionality for complex 3D landscape models – Lenné3D aims at filling this gap.

As most important benefits of real-time virtual landscapes we observed in application studies that they enhance the public participation in landscape planning, make the participation more interesting, and encourage the understanding of and the commitment to sustainable development and nature conservation. One subtle, possibly unconscious criterion of user acceptance represents the quality of both abstract and photorealistic 3D views, so that 3D editing and 3D plant features are essential for successful applications.

From software engineering perspective, our approach enables landscape and urban planners to integrate heterogeneous geodata, computer animation objects, and digital rights objects in a uniform framework. They become authors because they can export not only images but customized, distributed versions of virtual landscapes using the built-in Lenné3D-Xpress system. That is, a broad access to virtual landscapes such as needed in public participation processes can be implemented.

ACKNOWLEDGMENTS

Information on the Lenné3D system can be found on its web site at www.lenne3D.com; information on the editor system used in Lenné3D, the LandXplorer system, is located at www.landxplorer.net.

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